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# Tunability of Piezoelectric MEMS Ring Resonator Based Filter

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**Abstract**

The influence of piezoelectric actuator design on a two-port piezoelectrically transduced micro-electro-mechanical (MEMS) ring resonator frequency tuning performance has been investigated. A cubic silicon carbide (3C-SiC) ring resonator was fabricated with a lead–zirconium–titanate (PZT) piezoelectric actuator and sensor integrated on the surface of the ring. Measurements of the transmission frequency response have shown that the device with the ring diameter of 260 µm resonates at 1.082 MHz and a frequency tuning range of about 3,200 ppm has been achieved by applying DC bias voltage in the range 0 V – 6 V. Experimental results have shown that, under the same operating conditions, a wider frequency tuning range has been detected when the device was actuated and tuned with the piezoelectric actuator that covers a larger area of the ring surface and surrounds the central hole of the ring resonant structure.

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*Keywords:* MEMS resonator, Tunable filter, Piezoelectric actuation, Piezoelectric sensing

## 1. Introduction

MEMS resonators constitute a very promising technology for filter electronic components and quartz crystal replacement in high-end electronic systems [1]. However, the main problem of MEMS resonators is that the operating frequency could be shifted by changes in environmental conditions (temperature and pressure variations) or fabrication process tolerances (geometrical dimensions and material properties variations) [2]. The ability to actively tune the resonant frequency is therefore crucial for the resonators operation at a specific frequency.

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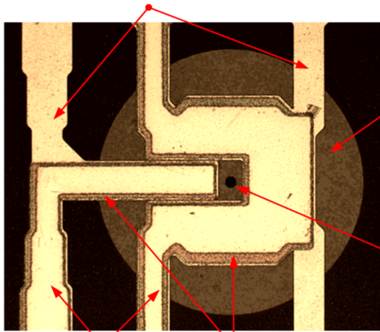


Fig. 1. Optical micrograph of the fabricated device with the Pt/PZT/Pt piezoelectric ports integrated on the surface of 3C-SiC ring.

Piezoelectric transduction technique is commonly used for electrical actuation and sensing of resonant vibration in MEMS resonators due to no need for DC voltage supply, strong electromechanical coupling and relatively simple fabrication process. Recently, we have demonstrated the fabrication and operation of piezoelectrically actuated and sensed cubic silicon carbide (3C-SiC) ring resonators [3]. 3C-SiC is one of the most suitable materials for MEMS resonators realization because of its excellent mechanical properties [4]. The active frequency tuning of piezoelectric MEMS resonators has been demonstrated in [5-7].

In this work, we investigate the influence of the piezoelectric actuator design on the frequency tuning performance of a two-port piezoelectric 3C-SiC ring resonator. The device has been fabricated with two significantly differently designed piezoelectric ports. Both ports have been used to perform piezoelectric actuation and sensing. By measuring the two-port transmission frequency response, comparison of the device's resonant performance actuated with each port has been conducted. FEM simulations have been performed to explain the frequency tuning behaviour of the device.

## 2. Experimental details

The device is constructed as a multilayer ring resonator with two piezoelectric ports integrated on the surface of 3C-SiC ring creating vertical flexural-mode resonator. The ports are formed of lead–zirconium–titanate (PZT) that is sandwiched between two platinum (Pt) layers. While the ports' vertical dimensions are equal, larger port covers about three times more area of the ring surface and surrounds the central hole of the ring resonant structure (Fig. 1). Both ports can be used for actuation and for sensing, allowing optimal conditions to perform comparative study of the actuator design influence on the device's resonant behavior.

The device was fabricated with the ring diameter of 260 μm and the central hole diameter of 10 μm. The device fabrication can be divided in three major phases: (i) deposition of 2 μm thick 3C-SiC layer on Si followed by Pt/PZT/Pt stack deposition with thicknesses of 100/500/100 nm; (ii) piezoelectric ports forming by etching the Pt/PZT/Pt stack; (iii) ring resonant structure forming by processing the 3C-SiC layer to open the circular hole in it for Si sacrificial layer release. The fabrication flow chart and physical dimensions are given in Fig. 2. Details of the fabrication of Pt/PZT/Pt/3C-SiC ring structures are presented in [3].

The device testing was performed with an HP 8753C vector network analyzer, which was SOLT calibrated in full 2-port configuration, and done in ambient conditions. The device was directly connected to the network analyzer with signal-ground-signal probes. The frequency tuning was performed by superimposing the actuating AC signal provided by the network analyzer to a DC signal provided by an external DC power supply. FEM simulations of the devices mechanical response under the applied tuning DC voltages were performed with *CoventorWare*.

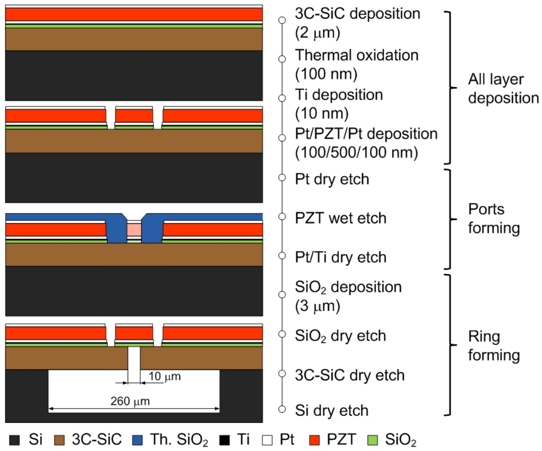


Fig. 2. : Fabrication flow chart with geometrical dimensions of the fabricated device.

## 3. Results and discussion

Transmission magnitude plots of the fabricated device are shown on Fig. 3a. The device was actuated with AC signal of 10 dBm and different tuning DC bias voltages applied to the small input piezoelectric port (left port in Fig. 1). An untuned resonant frequency (no DC voltage applied) of 1.082 MHz was detected and the frequency tuning range of about 650 ppm was obtained by application of DC bias voltage in the range 0 V - 6 V. However, when the device was actuated and tuned in the same way but with the large actuator, a frequency tuning range of about 3,200 ppm was obtained, as shown in Fig. 3b. The detected tunable capability is comparable to our previous work done on similar piezoelectrically transduced single-clamped beam [6] and double-clamped beam resonators [7]. While the obtained tuning range of the ring resonator is close to the double-clamped beam resonators, tunability of the single-clamped beam resonators is much smaller. This observation suggests that the resonant frequency shift of ring resonators, like as the double-clamped beam resonators, is more sensitive to surface induced stress changes than single-clamped beam resonators [8].

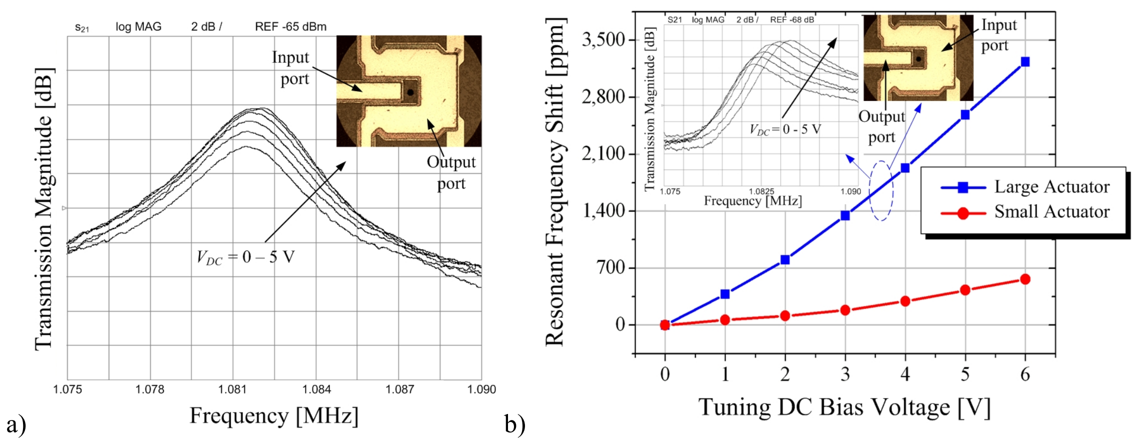


Fig. 3. (a) Transmission magnitude plots for different tuning DC bias voltages $V_{DC}$ applied to the small piezoelectric port (inset); (b) Measured resonant frequency shift versus piezoelectric tuning DC bias voltage for cases of actuation using the small port and the large port. The inset shows transmission magnitude plots for different tuning DC bias voltages $V_{DC}$ applied to the large piezoelectric port.

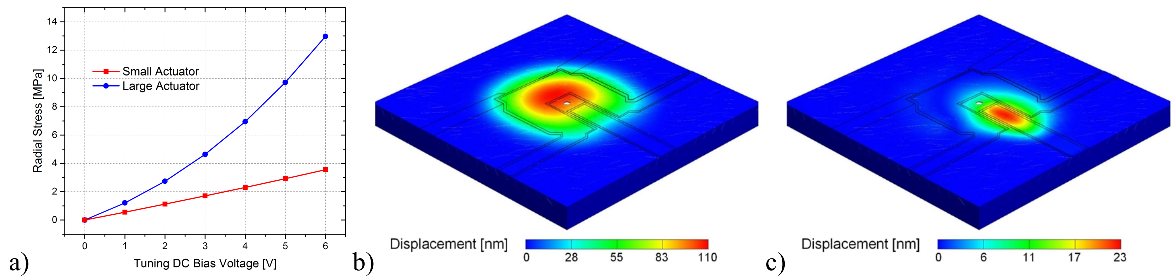


Fig. 4. (a) Simulated radial stress in 3C-SiC layer induced with the small and the large actuator; (b) Simulated vertical displacement of the ring structure induced with the large actuator; (c) Simulated vertical displacement of the ring structure induced with the small actuator.

In order to get a better understanding of the much wider tuning range measured with the larger actuator, simulations of the radial stress and vertical displacements of the ring structure were performed. Fig. 4a shows the comparison of simulated radial stress in the 3C-SiC layer, for different tuning DC voltages, induced with the small and the large actuator. As the tuning DC bias voltage increases, the difference in the induced stress progressively increases. The larger induced stress obtained when the device was actuated and tuned with the larger actuator is the probable cause of the wider frequency tuning range measured. In addition, actuation and tuning with the larger actuator has resulted in a larger vertical displacement and in deflection of a larger area of the 3C-SiC layer (Figs 4b and 4c), thus confirming a stronger resonant frequency shift.

## 4. Conclusions

The influence of piezoelectric actuator design on the frequency tuning performance of the two-port piezoelectric ring resonator has been investigated. The single device has been actuated and tuned with two differently designed piezoelectric ports. The measurements have shown that the device exhibits wider frequency tuning range when it was actuated and tuned with the larger piezoelectric actuator. The wider tuning range measured is attributed to a larger induced stress in the 3C-SiC resonant layer. FEM simulations have shown that in the case of actuation and tuning with the larger actuator a larger radial stress, a larger vertical displacement and deflected portion in the 3C-SiC layer have been observed. The results acquired with the single device and under the same operating conditions can be used to improve the frequency tuning performance of piezoelectric resonators.

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